



LTCS (Laser Thermal Control System) test supporting the improvement of DeCoM (Deepak Condenser Model) (Deepak Patel / NASA GSFC)

Presented By
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Lead Thermal Engineer on ATLAS
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Sr. Thermal Engineer at GSFC
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Loop Heat Pipe Expert
- **Thermal Engineering Branch at Goddard Space
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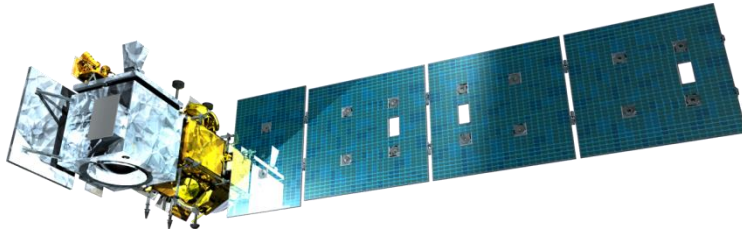
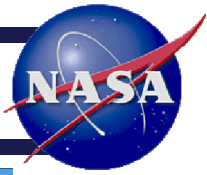


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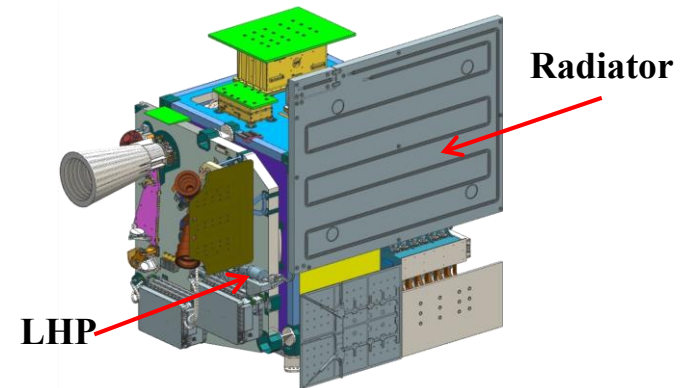
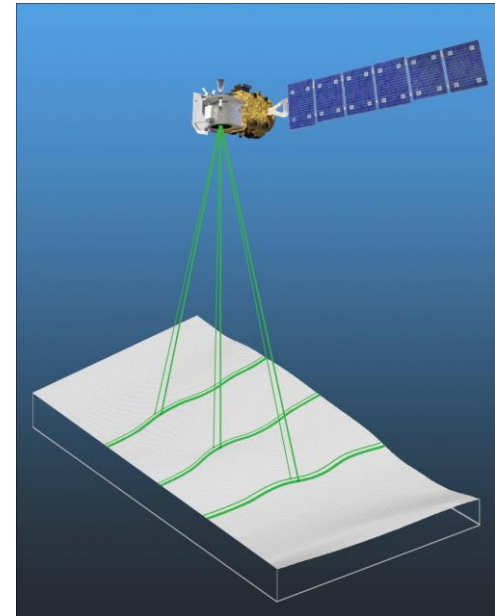


ATLAS Introduction

Science Objective/LTCS Purpose



- The objective of ICESat-2 is to collect altimetric measurements of Earth's surface, optimized to measure heights and freeboard of polar ice.
- ATLAS (Advanced Topographic Laser Altimeter System) instrument, sole for the mission, carries two lasers onboard. Only one laser is operational at any given time. The test that this presentation will cover is of the LTCS (Laser Thermal Control System) that was designed to maintain temperature of the operational laser.



LTCS Assembled with ATLAS



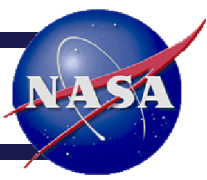
LTCS Test Description



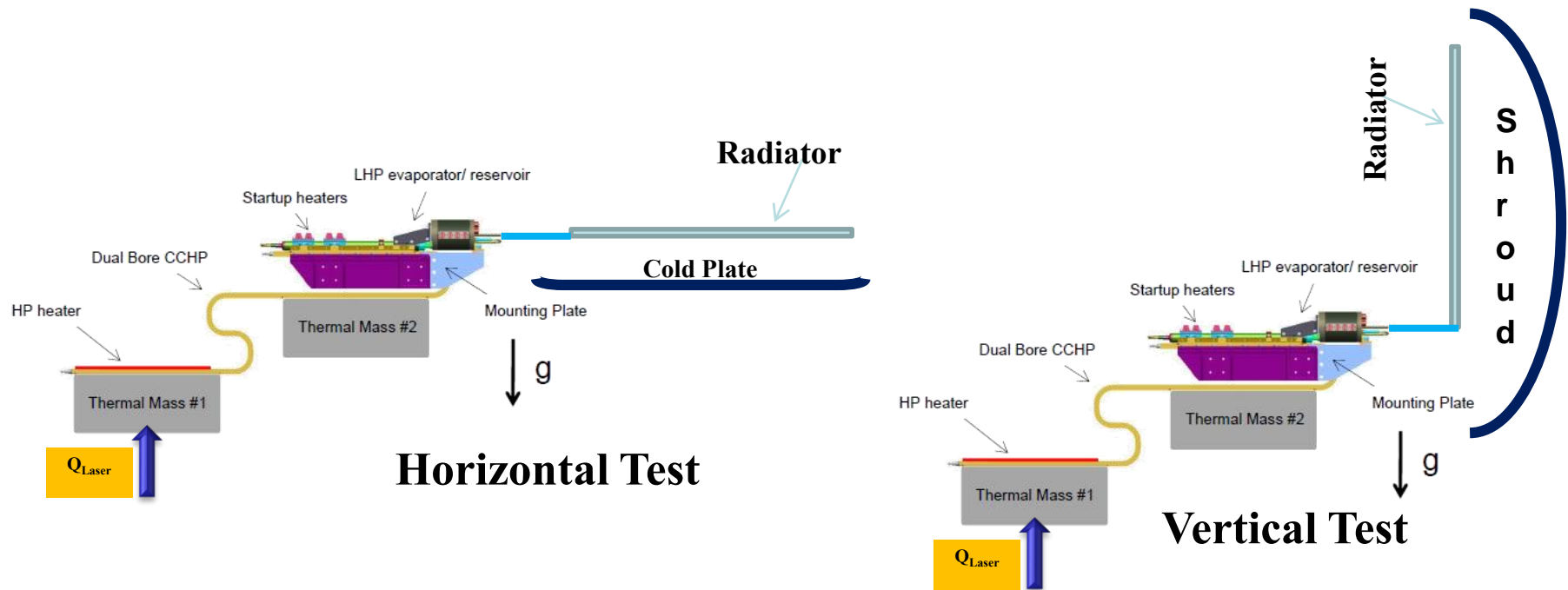
- December 2013
 - The first test of LTCS did not complete due to gravity induced effects
 - The reservoir control heater was at 100% duty cycle with no control on the reservoir.
- June 2014
 - Re-test was performed with a horizontal configuration of the system where gravity effects would not play a role in affecting the system pressure. Another configuration which would allow a heater to warm up the liquid return line to gain control on the reservoir.



LTCS Test Description

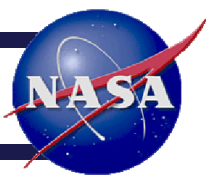


- Flight laser thermal control system (LTCS) comprises of a loop heat pipe, constant-conductance heat pipe, and a radiator
 - Heat pipe and LHP both operating in reflux
 - The test comprises of thermal masses that have similar capacitance that of the flight lasers.
 - The radiator coated surface was the only exposed area to the shroud, everything else was blanketed.
- Thermal Testing was performed in horizontal configuration for system verification with gravity neutral. Vertical configuration was performed for higher levels of testing verification.

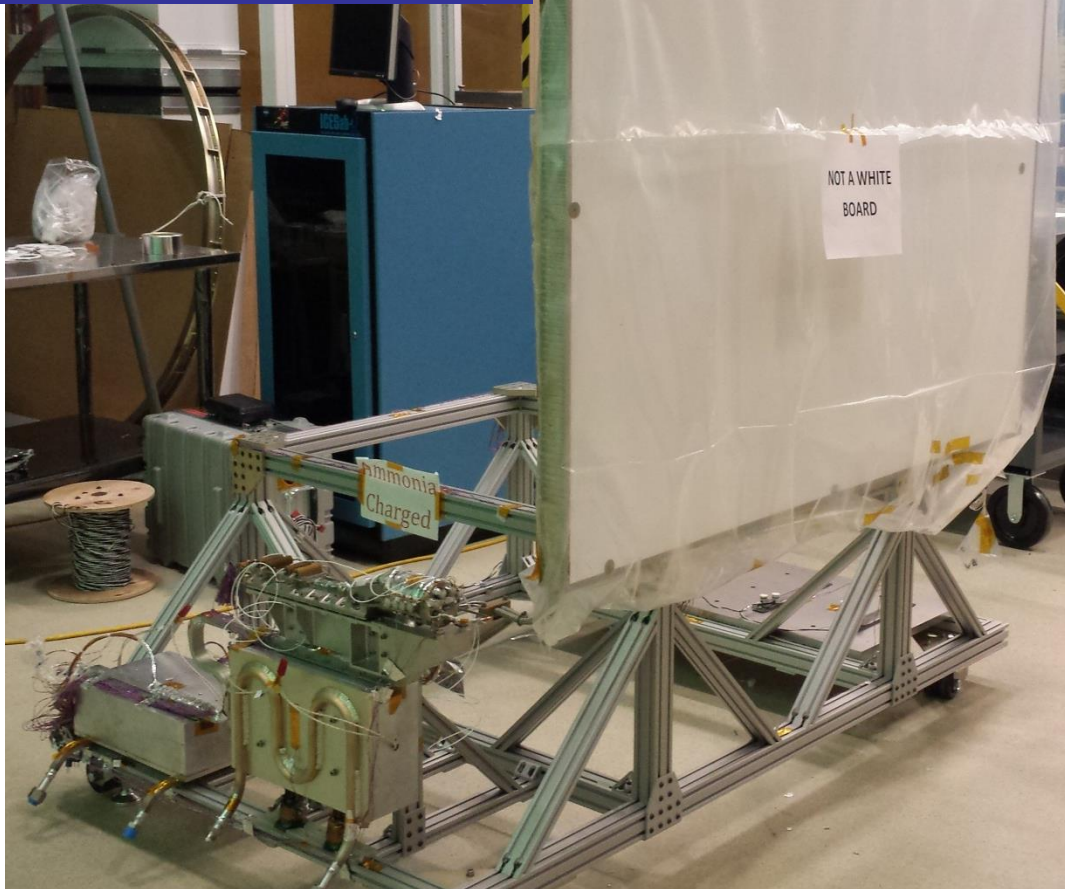




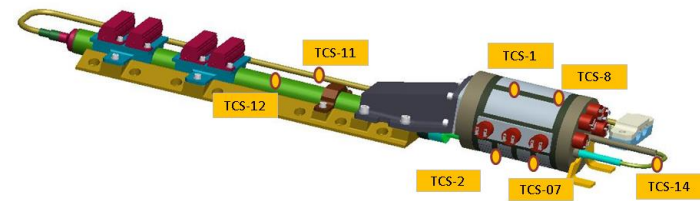
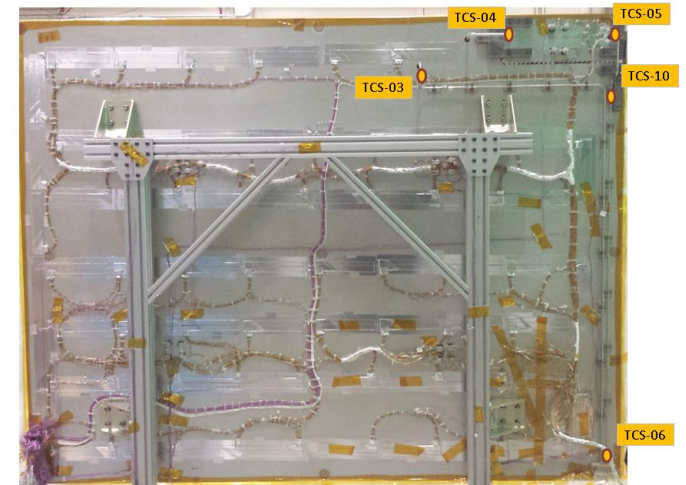
LTCS Test Description



Test Hardware (Vertical Orientation)



Test Temperature Sensors

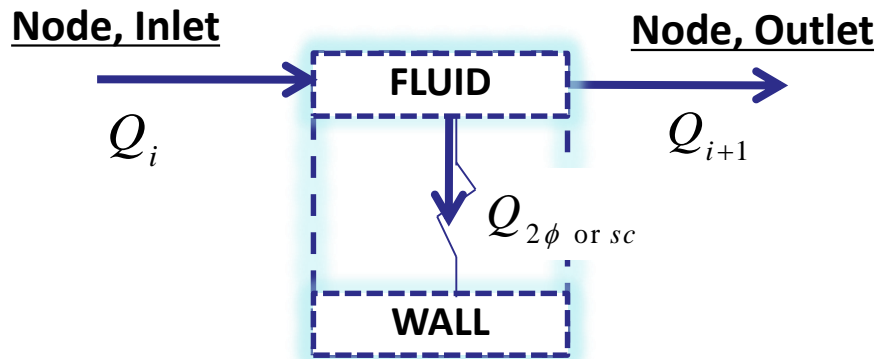




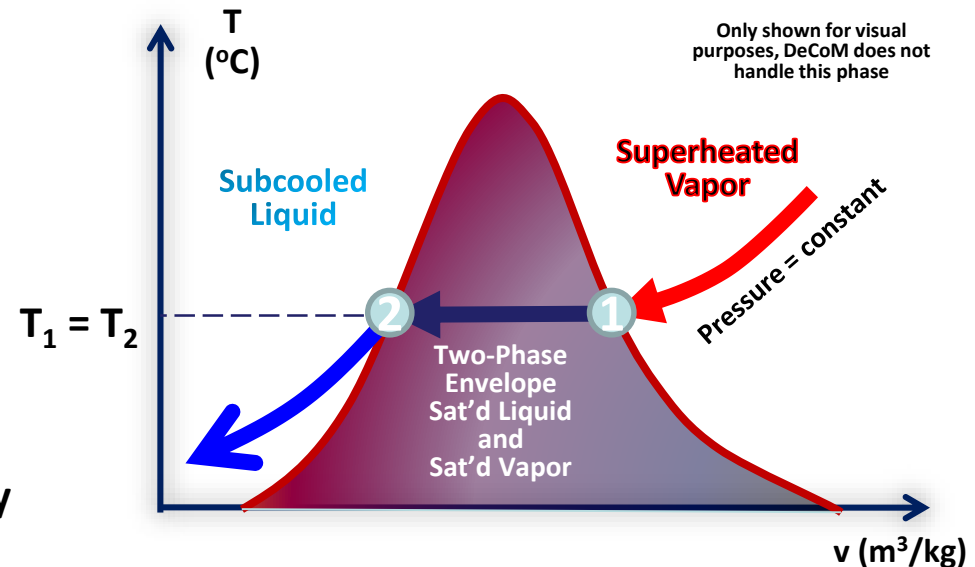
DeCoM Introduction



- DeCoM was developed through the need to predict fluid behavior. Benefit of DeCoM over other software's was that it was home grown, and no licenses were required.
- DeCoM Theory:



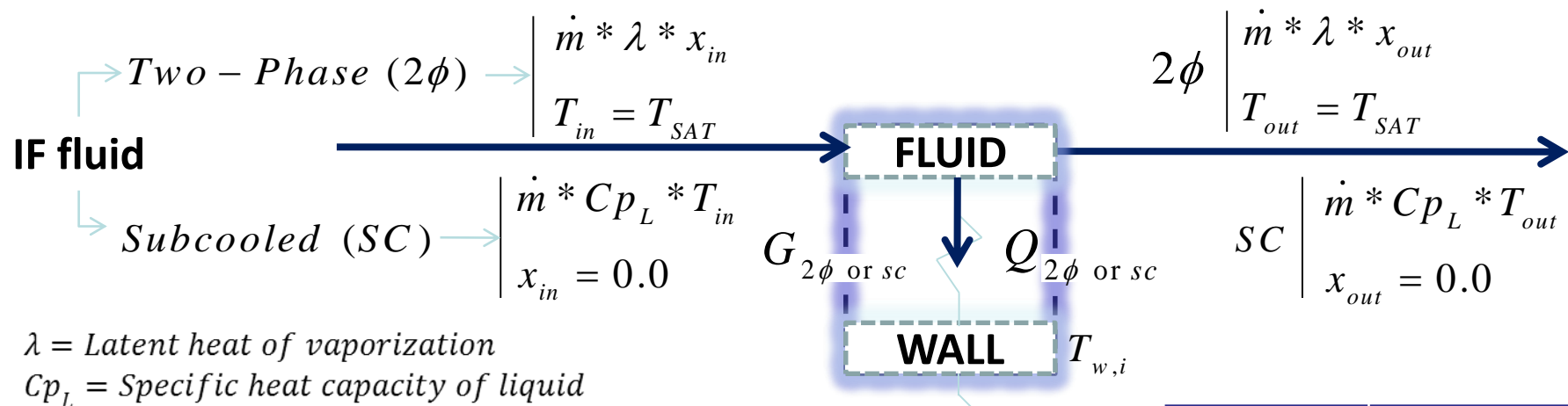
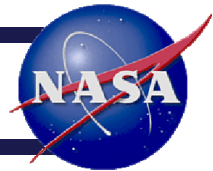
$$\sum Q_{in} = \sum Q_{out} \quad \text{➤ Conservation of Energy}$$



- Condenser source code is based on the Conservation of Energy equation. Applied on each node.



DeCoM Introduction – Governing Equations



$$Q_{2\phi} = \dot{m} * \lambda * \Delta x$$

➤ 2-Phase section

$$Q_{sc} = \dot{m} * Cp_l * \Delta T$$

➤ Subcooled section

UNKNOWN	KNOWN
X_{out} if 2ϕ	T_{wi}, T_{fi} X_{in} $G_{2\phi}(x_{in})$ $Q_{2\phi}(G_{2\phi}, T_{wi})$
T_{OUT} if SC	T_{wi} T_{IN} G_{SC} $Q_{SC}(G_{SC}, T_{wi})$

- Inlet conditions are known
- Equations can vary depending upon the state of the fluid (2ϕ or SC), as shown above.
- *Lockhart-Martinelli* equations are used to solve for the $G_{2\phi}$ value.



- A new feature that's been added to the code allows the user to let the code decide what correlation method to apply for verifying phase transition.
 - The user can also manually select one of 5 of the following methods, pre-built into the code:
 - Muller-St and Heck Correlation
 - Shah Correlation
 - Lockhard and Martinelli Correlation
 - Results closely match test data using this method
 - Friedel Correlation
 - Chisholm Correlation
- The code chooses the correlation method based on ratio of liquid and vapor dynamic viscosity, and mass velocity.
 - This approach was tested by Whalley (1980) with extensive comparison between various published correlations (with over 25,000 data points)
 - Ref: Wolverine Tube, Inc Engineering Data Book III

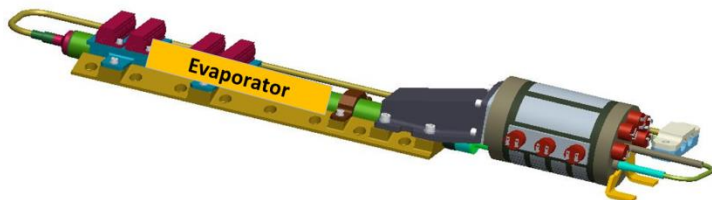
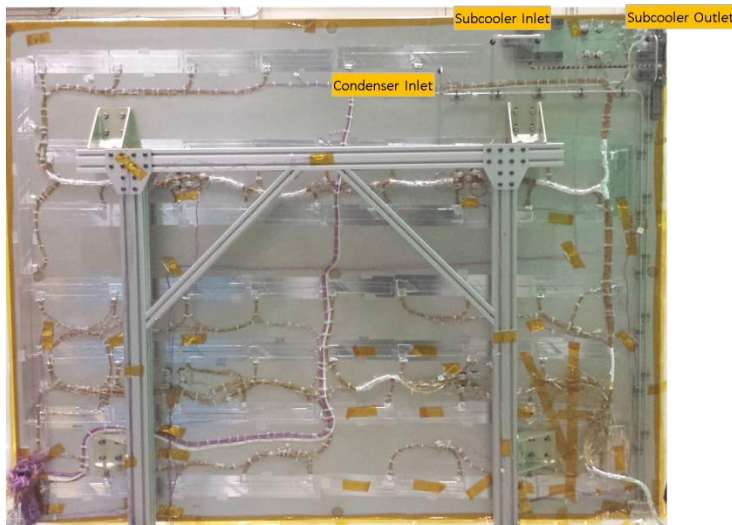


DeCoM Predictions



- Data comparison shows that DeCoM predicted temperatures of the condenser line within a degree on average.

Test Temperature Sensors



Horizontal Test Data Correlation

<u>Sensor</u>	<u>Test Data</u>	<u>DeCoM (Thermal Model)</u>	<u>DT</u>
[C]			
<u>Balance 1H</u>			
Evaporator	13.54	13.61	-0.07
Condenser Inlet	11.15	13.61	-2.47
Subcooler Inlet	-9.04	-10.62	1.58
Subcooler Outlet	-16.37	-16.9	0.53
<u>Balance 2H</u>			
Evaporator	8.58	8.61	-0.03
Condenser Inlet	6.29	8.61	-2.32
Subcooler Inlet	-16.38	-13.88	-2.50
Subcooler Outlet	-21.36	-20.47	-0.89
<u>Balance 4H</u>			
Evaporator	-13.35	-13.61	0.26
Condenser Inlet	-14.47	-13.61	-0.86
Subcooler Inlet	-25.14	-23.11	-2.03
Subcooler Outlet	-26.79	-27.19	0.40
<u>Balance 9H</u>			
Evaporator	-6.27	-5.48	-0.79
Condenser Inlet	-7.38	-5.48	-1.90
Subcooler Inlet	-18.56	-16.62	-1.94
Subcooler Outlet	-20.36	-21.47	1.11
<u>Balance 10H</u>			
TCS-12	6.85	6.39	0.46
TCS-03	5.33	6.39	-1.06
TCS-04	-10.84	-9.3	-1.54
TCS-05	-12.87	-15.51	2.64

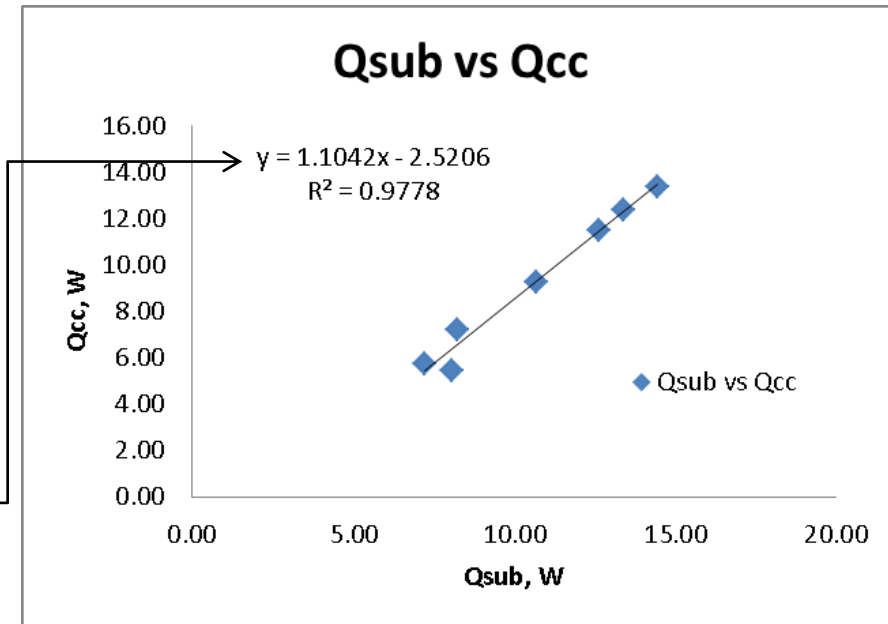


DeCoM Predictions



- Further correlation proved that the Q calculated from the subcooled liquid can be compared to the control heater power. This comparison can aid in predicting control power based on the DeCoM subcooling temperatures.
- Using control power retrieved from test data and subcooled line temperatures, a linear relation was formulated.

Test Data



Qsubcooled calculation:

$$Q_{sub} = C_p * \dot{m} * (T_{in} - T_{out})$$

$$C_p = \text{Specific heat capacity of liquid, } \frac{J}{kg * K}$$

T_{in} = Inlet temperature, C

T_{out} = Outlet temperature, C

Q_{sub} = Subcooling heat, W



DeCoM Predictions



- Using the linear equation formulated from test data, DeCoM was utilized to calculate the control power required based on the subcooling from the condenser line.
- The following table shows how closely the control power was predicted with DeCoM:

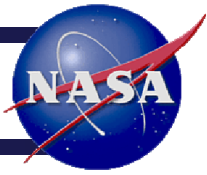
**Qsub based on DeCoM
output**

**Qcc predicted based on
Qsub from DeCoM**

	Q total	Tcc	Ttm1	Qcc	Qsub	Qcc_Qsub _predicted	% Difference
	W	C	C	W	W	W	
Balance 1H	136.0	14.5	30.6	13.37	14.47	13.46	1%
Balance 2H	136.2	8.3	25.3	12.35	13.39	12.26	1%
Balance 4H	196.0	-14.2	10.3	5.44	8.06	6.38	15%
Balance 7H	150.0	-0.8	19.5	9.25	10.71	9.30	1%
Balance 8H	150.0	-1.0	19.4	7.22	8.25	6.59	10%
Balance 9H	170.0	-7.6	14.8	5.74	7.22	5.45	5%
Balance 10H	196.0	6.0	29.9	11.50	12.63	11.43	1%



Future Work



- Make the code more user friendly
 - Compile the code for better file transport
 - Combine two files into one
 - Currently there is a file for creating thermal network and one for performing fluid calculations
- Correlate more data points for reliability
 - Increase code confidence
- Include pressure drop calculations
 - Be able to calculate condenser pressure drops for use towards the larger loop heat pipe system pressure drop calculations.